

# REPLACING ODCs IN A CRITICAL HAND CLEANING MANUAL ELECTRONICS ASSEMBLY OPERATION

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## Abstract

The manufacture of high reliability electronics assemblies for spacecraft and ground support equipment still often involves manual assembly processes. In addition, rework and repair of critical assemblies also often entails manual assembly techniques. For high reliability applications, cleaning is a must. Traditionally, ozone depleting chemicals (ODCs) have been used to perform cleaning of these critical assemblies. Since ODCs are no longer acceptable, an investigation was pursued to replace ODCs in the operation of hand cleaning of manual electronics assemblies and cable harnesses. This case study reviews the process of how a different cleaning agent was selected to replace ODCs. It discusses both the internal and external criteria to which the new agent had to conform to be acceptable as a suitable replacement. This study also treats the historical background, process development, and the different technologies that were scrutinized to find a successful replacement to meet the demands of spacecraft electronics. Technical data and findings dealing with the different approaches are presented. The information provided can also be applied to manual hand cleaning following rework and repair operations.

## Key Words

Ozone depleting chemical (ODC), ozone depletion potential (ODP), circuit card assembly (CCA), printed wiring board (PWB), electronics assembly, cable harness, 1,1,1-trichloroethane (methyl chloroform, TCA), permissible exposure limit (PEL), eight-hour time weighted average (8-hr TWA), semi-aqueous (SA) cleaning agent, solvent cleaning agent, isopropyl alcohol (IPA), cable harness, flux residue, ionic residue, ionic contamination testing, hydrochlorofluorocarbon (HCFC), hydrofluorocarbon (HFC), volatile methyl siloxane (VMS), hydrofluoroether (HFE), flash point (F.P.), volatile organic compound (VOC), outgassing.

## Introduction

The Electronic Packaging and Fabrication Section at the Jet Propulsion Laboratory currently produces various types of CCAs and cable harness assemblies. In many cases, components are still manually soldered to the PWB surface to create the completed CCA, and cable harness assembly often entails manual soldering. The compound 1,1,1-trichloroethane (methyl chloroform, TCA) has been used for a number of years as the cleaning agent of choice for removing flux residues. This material has very good cleaning power, a not too overpowering odor, and its PEL, being set at 350, is acceptable for use in the work environment. However, the ODP of TCA is 0.15. Although this number is relatively low, compared to 1.0 for CFC-11 and 0.8 for CFC-113, because such large quantities were consumed, it was placed in Category I Group V and its production was slated to be phased out at the end of 1995. Because hydrochlorofluorocarbon (HCFC) 141-b has about the same ODP as TCA (see Table 1), it was considered unacceptable. In addition, production of HCFC 141-b will cease as of January 1, 2003.

In early 1994, the Jet Propulsion Laboratory's Electronic Packaging and Fabrication Section initiated a project to find an acceptable alternative to TCA as a cleaner in the manual electronics assembly operation.

**Table 1: Boiling Points and ODPs of Three Ozone Depleting Chemicals**

Solvent	b.p. °C	b.p. °F	ODP
CFC-113	47.6	117.6	0.8
1,1,1-trichloroethane (TCA, methyl chloroform)	74.1	165.4	0.15
HCFC-141b	32.0	89.7	0.12

## **Cleaning Activities in JPL's Electronic Packaging and Fabrication**

Two distinct types of hand cleaning are performed at JPL. These are: the hand cleaning of circuit card assemblies while they are being assembled and after assembly is complete, and the cleaning of cable harnesses. Figure 1 shows a technician in the process of manually assembling a CCA. Figure 2 shows a group of technicians involved in manual assembly operations. In the case of cable harnesses, huge wiring mock-ups are fabricated by technicians. Figure 3 shows a technician manually assembling cable harnesses on one of the mock-ups. It is not possible to move these mock-ups under fume hoods. Semiautomated batch cleaning of surface mount CCAs is also performed, although that operation takes place in a different room.

Manual cleaning is generally performed by a technician at his/her workstation. The equipment used is a small bottle to dispense the liquid cleaning agent and a hand brush to wipe away flux residue. After assembly is complete, the entire CCA is removed to another room, where cleaning takes place under a hood using a brush, a cleaning agent, and a glass dish to catch excess cleaning agent.

Because of the diverse nature of the cleaning activities at JPL, a particular cleaning agent must meet certain internal and external criteria in order to be acceptable as a suitable replacement for 1,1,1-trichloroethane. However, the goal and particular criteria of the Electronic Packaging and Fabrication section at JPL may differ somewhat from the goal and criteria of other sections at the Laboratory, such as Propulsion and Spacecraft Mechanisms.

## **Goal for JPL's Electronic Packaging and Fabrication Section**

The goals of JPL's Electronic Packaging and Fabrication section are:

- Replace 1,1,1-trichloroethane in cleaning CCAs that have been manually assembled.
- Replace 1,1,1-trichloroethane in the hand cleaning of cable harnesses.
- If feasible, find one cleaning agent that meets all of the section's cleaning goals.

## Purpose of Cleaning in Electronics

It should be kept in mind that the chief form of contamination in producing electronic assembly hardware is contamination left from the soldering operation. In particular, this contamination consists of flux residues, and in the case of surface mount CCAs, paste residues.

The use of flux, or paste, is very important in producing an acceptable solder joint. The action of the flux is required for the following reasons:

- Interact with metals to remove oxides from the surface of the metals and render them active so that a strong metallurgical interconnect can be formed between the lands on the PWB and the component leads.
- Form a reducing vapor, or at least a blanketing vapor, during the soldering process to prevent the reoxidation of the surfaces while soldering is taking place.
- Assist the even spread and wetting of the solder while the metallurgical interconnection is being made.

In addition to these three points, solder paste also contains the actual solder used to form the interconnect.

Practically all fluxes, and pastes, contain materials known as activators. These materials are the active ingredients that perform the above tasks of rendering the flux suitable for creating a good solder joint, or electrical interconnect. In general, the higher the activator loading, the better the flux, or paste, performs in the soldering process. Unfortunately, the residues left from these activator materials after the flux/soldering process can often cause problems on electronic hardware if they are not cleaned properly. In fact, activator residues have been directly pinpointed as the cause for corrosion, leakage currents, and the degradation of surface insulation resistance.

Residues, if not removed prior to the application of a conformal coat, can lead to the formation of vesicles, or small blisters, under the conformal coating. Typically, these vesicles are caused by the ingression of water molecules through the conformal coating material due to the attraction of the water for hygroscopic, ionic materials left after the fluxing operation. The buildup of osmotic pressure as the water forms weak hydrogen bonds with the ionic material can actually cause the conformal coating to lift, thus leading to vesicles. The process is called mealing, or vesication. It is clearly indicative that certain residues were not properly removed prior to applying the conformal coating.

It should also be born in mind that the bare PWB can also contain residues that should have been removed but sometimes are not. Such residues as plating and etching salt residues, activators from the solder reflow process or the hot air solder leveling (HASL) process, and photoresist residues are sometimes found on the bare PWB.

Other sources of contamination are: handling, particularly by humans, and particulates that can arise from either processing, handling, or which are air-born.

## Internal and External Criteria

Finding a new cleaning agent can be challenging. In particular, at JPL there were a number of both internal and external criteria that any new agent first had to meet in order to be acceptable.

The internal criteria were:

- The new cleaning agent must clean as well or better than TCA using both visual inspection criteria and ionic contamination testing criteria.
- The new cleaning agent must have an ozone depletion potential (ODP) less than 0.05 (TCA's ODP = 0.15).
- The new cleaning agent must be deemed safe to use, especially for hand cleaning operations.
- The new cleaning agent must exhibit good material compatibility with a wide variety of materials used in electronics fabrication and assembly.
- The new cleaning agent should be capable of being used in a suitable piece of cleaning equipment and neither present a hazard, e.g., flammability, nor emit undue losses to the atmosphere.
- The new cleaning agent must not have a disagreeable odor, making it obnoxious to use in a hand cleaning operation.
- The new cleaning agent must evaporate at an acceptable rate.
- The new cleaning agent must not exhibit unacceptable outgassing characteristics using typical flight connectors and PWAs.

The external criteria were:

- The new cleaning agent must be granted, or already have been granted, SNAP (Significant New Alternatives Program) approval by the U.S. EPA.
- The new cleaning agent should not be considered a volatile organic compound (VOC) by California's South Coast Air Quality Management District (SCAQMD).
  - If the new cleaning agent does contain some VOCs, it must be granted exemption by SCAQMD.

### **First Set of Candidate Cleaning Agents**

Back in the summer of 1994, an initial investigation was conducted to find a suitable replacement for 1,1,1-trichloroethane. At that time, a number of different chemistries were on the market, many of them classified as semi-aqueous. That is, they consisted of either a terpene-based or nonterpene-based material, such as various alcohol mixtures, but the final rinsing agent was generally water or a low molecular weight alcohol. At JPL's Electronics Packaging and Fabrication facility, at least fifteen (15) different materials were examined. Most of the materials used in the initial evaluation had a zero (0) ODP.

### **Test Procedure—Hand**

The test procedure followed was identical for each cleaning agent. Five hundred microliters (500  $\mu$ l) of an RMA flux were placed on each PWB to be tested. The flux was allowed to dry on the board for six hours before testing began. The board was then cleaned for one minute using fresh cleaning agent and a hand brush. Four PWBs were cleaned per each cleaning agent. Two of the boards were then placed in a suitable ionic contamination tester and two were sent for visual inspection.

### **Test Procedure—Beaker**

Again, the test procedure followed was identical for each cleaning agent. The PWBs with flux were prepared the same way as for the hand cleaning test. Each board was cleaned for one minute using a beaker full of fresh cleaning agent. The cleaning agent in the beaker was agitated and heated if this was recommended by the manufacturer. All four PWBs with hardened flux per cleaning agent were placed sequentially in that cleaning agent. After cleaning in the cleaning agent, each board was rinsed for thirty seconds using isopropyl alcohol (IPA) twice. Again, two of the boards were then placed in a suitable ionic contamination tester and two were sent for visual inspection.

Data from the ionic contamination tester were also gathered taken from boards covered with flux and cleaned only with the two IPA rinses to determine how much contamination was actually removed by the IPA.

### **Visual Inspection**

For visual inspection, a code was given to the inspector for assigning the results of the visual inspection. This code was:

- 1      No contamination.
- 2      Slight contamination.
- 3      Moderate contamination.
- 4      Heavy contamination.
- 5      No flux removed.

For each board inspected, the inspector assigned the board one of the above numbers and wrote down any additional comments about the board.

### **Results of First Set of Candidates**

The first stage eliminated the cleaning agents whose boards showed an unacceptably high level of ionic contamination and/or visually exhibited a large visible flux residue after cleaning. Also, those solvents having an objectionable odor, caused dizziness, or shortness of breath were eliminated. At this first stage, ten (10) of the fifteen candidates were eliminated. One candidate, a solvent, was not eliminated; rather, it was put on the back-burner, so to speak, because of its cost. Since this material was a new solvent functioning very much like a conventional solvent, in this paper it will be designated as Solvent #1. This material is discussed in more detail below. See Second Set of Candidate Cleaning Agents.

The second stage of the investigation centered on the remaining four candidates. However, rather than just apply flux and allow it to stand for six hours (see above: Test Procedure—Hand and Test Procedure—Beaker), the flux was baked on at 350°F for five (5) minutes. Two of the products exhibited some material compatibility problems. Thus, these two were also eliminated. The third material, semi-aqueous, was deemed fit for batch cleaning, but not for hand cleaning.

The investigation thus down-selected to one remaining material, a petroleum-based distillate containing a mixture of mixed aliphatic hydrocarbons (app. 36-60 wt.%) and a high molecular weight alcohol (1-propoxy-2-propanol). This cleaning agent is classified as a semi-aqueous material by the manufacturer, indicating that it should be rinsed with water or a low molecular weight alcohol, such as IPA. In this paper, this material will be designated as Semi-aqueous Agent #1.

This material was considered, at first cut, to show good cleaning results based on both the ionic contamination test and visual inspection. In addition, it exhibited a mild odor reminiscent of baby powder and was not found objectionable in this regard. Its ODP was zero, and it was not overly expensive.

Semi-aqueous Agent #1 did, however, have several drawbacks. Although it was a good cleaner, it did not readily evaporate. Also, it had a low flash point (F.P.), namely, 44°C (111°F), so it definitely could not be used in a traditional vapor degreaser. Equipment that could hold Semi-aqueous Agent #1 was carefully examined; however, the equipment was not deemed acceptable by several of the manufacturing engineers. The equipment was judged to exhibit too many unacceptable features:

- Clumsy operator interface.
- Large footprint.
- Difficult to operate.
- The equipment was pneumatically driven (to minimize the flammability hazard), but the volume of air required was greater than the plant air available at the use-site.

In addition, an outgassing test performed using a fluorosilicone grommet/connector exhibited very high outgassing characteristics. Gas chromatographic (GC) analysis revealed that Semi-aqueous Agent #1 was a complex mixture of different chemical ingredients, containing approximately 20 different chemical species. See Figure 4.

## **Second Set of Candidate Cleaning Agents**

Because of the problems associated with Semi-aqueous Agent #1, it was decided to reexamine the issue and determine whether a different sort of cleaning agent would suffice. In the meanwhile, a number of new cleaning agents also emerged in the marketplace, and several of these appeared promising as potential candidates for replacing TCA in the electronics hand cleaning assembly operations. In addition, Solvent #1, which was mentioned above, had given good results. It was eliminated initially because of its high cost. However, it was reconsidered, along with some of the newer solvent materials that were beginning to emerge.

In 1995-96, several other cleaning options were available and were investigated:

- Carbon dioxide impingement cleaning.

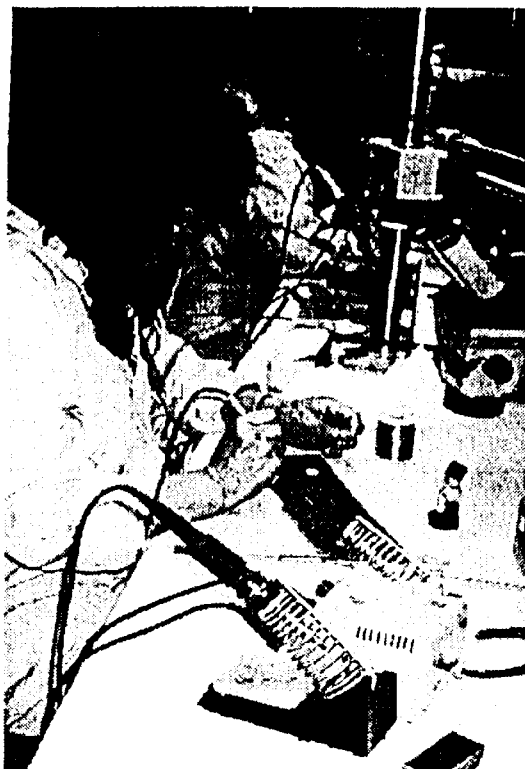


Figure 9 Different technician simulating hand assembly for TWA testing



Figure 10 Technician cleaning final assembly for TWA testing



Figure 7 The author and a member of JPL's Environmental Affairs Section observe the technicians' activities during the 8-hr TWA test

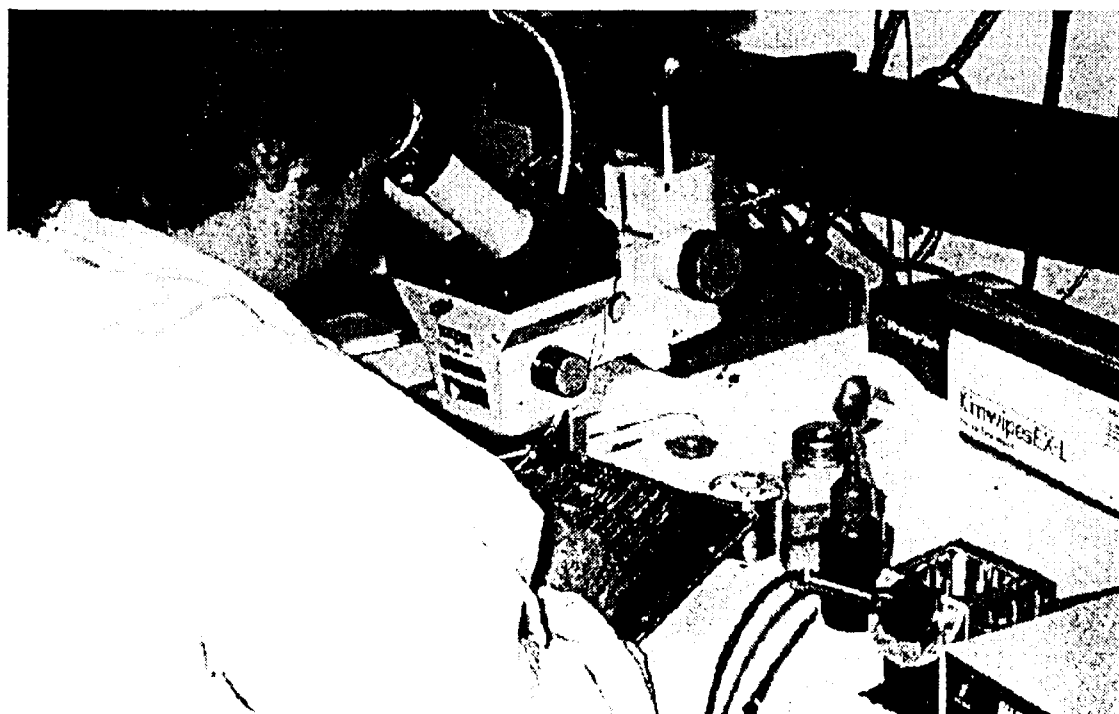


Figure 8 Technician simulating hand assembly for 8-hr TWA testing





Figure 5 The authors discuss a point prior to initiating the 8-hr TWA test



Figure 6 Technicians at their work stations during 8-hr TWA testing

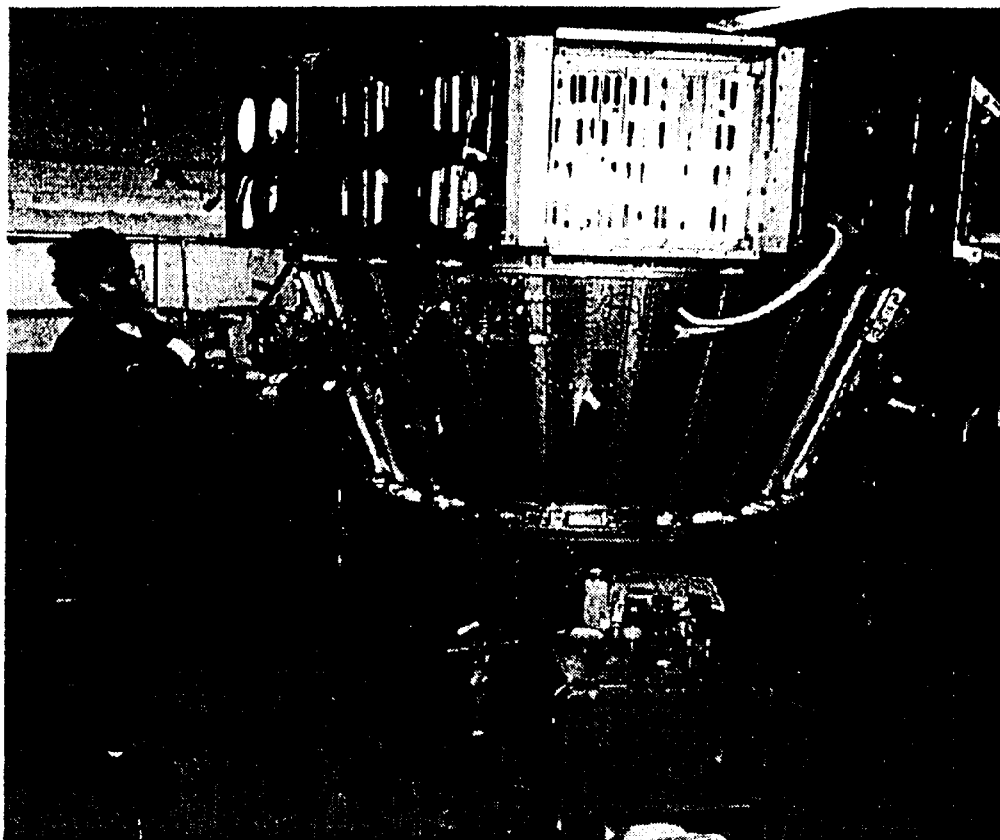


Figure 3 Technician completing cable harness assembly on mockup

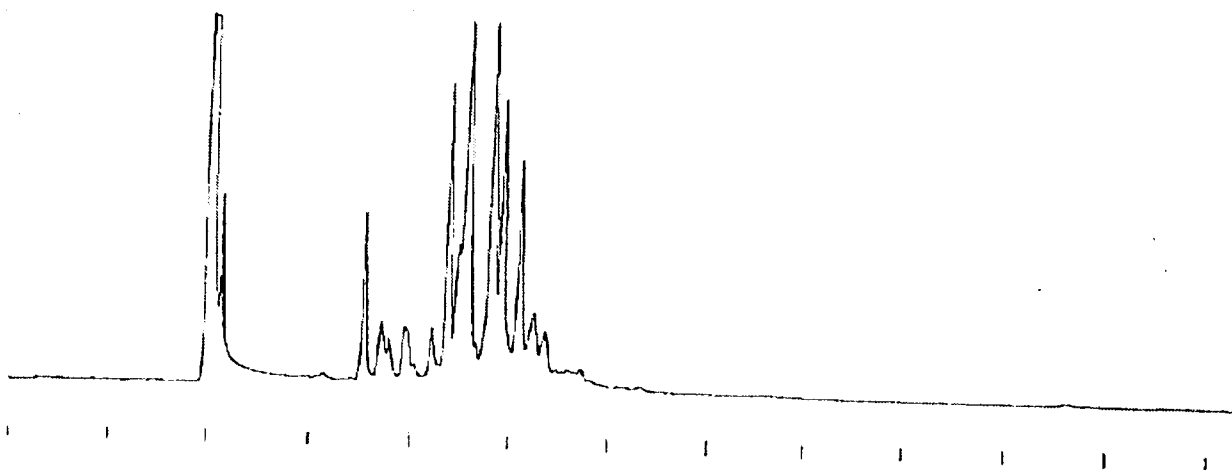


Figure 4 Gas chromatographic analysis of Semi-aqueous Agent #1



Figure 1 Technician performing hand assembly on a PWB



Figure 2 Technicians conducting manual PWB assembly

- Very good material compatibility with a number of different polymers and metals.
- No significant global warming potential.
- Can be used in a conventional vapor degreaser. However, a degreaser having a minimum of 100% freeboard, extra chilling coils, and a suitable rolltop cover are highly recommended to keep solvent losses at a minimum.

In the case of Solvent #2-M, the following disadvantages pertain:

- Very high VOC loading, approximately 47 wt.% of the formulation is VOC. This may pose a problem in some locations.
- Expensive—est. cost ~\$140–\$145/gal. (5-gal pail quantities).  
Note: Solvents are sold on a weight basis, not on a volume basis. A 5-gal pail contains 51.0 lb.; the manufacturer's recommended price for this quantity is \$13.95/lb.

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- 4 Solvent #1-M did a good job of cleaning. Solvent #2-M tended to shift the flux away and leave the board sticky, more solvent was required to clean the board.
- 5 Both solvents evaporate at an acceptable rate.

**The conclusions to be drawn:**

(1) In the case of Solvent #1-M, the following advantages pertain:

- Regarding cleaning power, Solvent #1-M  $\approx$  1,1,1-trichloroethane, whereas Solvent #2-M  $<$  1,1,1-trichloroethane.
- Easy to use. It is a direct replacement for solvents based on CFC-113 and for TCA.
- Very good material compatibility with a number of different polymeric and metals.
- No significant global warming potential.
- Can be used in a conventional vapor degreaser. However, a degreaser having a minimum of 100% freeboard, extra chilling coils, and a suitable rolltop cover are highly recommended to keep solvent losses at a minimum. There is a caveat regarding using this material in a degreaser. See below.

In the case of Solvent #1-M, the following disadvantages pertain:

- Low PEL. During the 8-hr TWA test, two of the five technicians exceeded the PEL which is currently set at 50 ppm. However, proper training could probably reduced the exposure so that it could be kept under 50 ppm. This is evident since three of the technicians managed to stay well under the 50 ppm limit.
- Finite ODP of 0.03—therefore, production will eventually cease (the current phaseout date is currently set at January 1, 2015).
- Expensive—est. cost ~\$125–\$135/gal. (5-gal pail quantities).  
Note: Solvents are sold on a weight basis, not on a volume basis. A 5-gal pail contains 44.1 lb.; the manufacturer's recommended price for this quantity is \$14.15/lb.
- Although it can be used in a conventional vapor degreaser, the particular formulation is not azeotropic. That is, it may be subject to fractionation, leading to an unacceptable buildup of its flammable ingredients, especially the cyclohexane. However, precautions can easily be taken to prevent this from occurring.

(2) In the case of Solvent #2-M, the following advantages pertain:

- Also a good cleaner, but probably not quite as good as Solvent #1-M.
- Zero (0) ODP. Therefore, there is no phaseout date.
- Easy to use. It is a direct replacement for solvents based on CFC-113 and for TCA.

through the tube. The tubes were analyzed using gas chromatography to determine the amount of solvent to which each technician was exposed. However, the test was set up and conducted by the personnel of the manufacturer producing Solvent #2-M. The results are presented in Table 3 above; the figures given in Table 3 (Row 2) are only for the amount of HFC to which each technician was exposed.

## Conclusions

The two solvents that were closely scrutinized as suitable replacements for 1,1,1-trichloroethane in manual electronics assembly are:

1 Solvent #1-M:

- HCFC Isomer #1 38.3 wt.%
- HCFC Isomer #2 46.8 wt.%
- Cyclohexane 10.0 wt.%
- Ethyl alcohol (EtOH) 4.5 wt.%
- Stabilizers 0.4 wt.%.

2 Solvent #2-M:

- HFC 53.5 wt.%
- Trans-1,2-dichloroethylene (t-DCE) 25.0 wt.%
- Cyclopentane 15.0 wt.%
- Methanol (MeOH) 6.0 wt.%
- Nitromethane (MeNO<sub>2</sub>) 0.5 wt.%.

Both of these solvents are not perfect replacements for 1,1,1-trichloroethane. Both can be used in a conventional vapor degreaser (see the caveat below regarding Solvent #1-M). However, because both are expensive, the degreaser ought to be provided with extended freeboard, an extra set of chilling coils, a roll-away cover, etc. to help prevent undue solvent losses to the atmosphere.

During the 8-hr. TWA test, each technician was asked to assess each solvent. The questions to which they were to respond were:

- 1 Is it as easy to use overall as 1,1,1-trichloroethane?
- 2 Does it clean as well as 1,1,1-trichloroethane?
- 3 Did you dislike its odor?
- 4 Is there anything else you noticed about it that you didn't like?
- 5 Any other comments?

The responses returned were:

- 1 Both were, overall, as easy to use as 1,1,1-trichloroethane.
- 2 In general, Solvent #1-M cleaned better than Solvent #2-M. See Comment 4.
- 3 Solvent #1-M is equivalent in odor to 1,1,1-trichloroethane, whereas Solvent #2-M has little or no odor. See Table 2.

## 8-Hr. Time Weighted Average Testing

The following two solvents were tested to determine their 8-hr. time weighted average (TWA):

- Solvent #1-M.
- Solvent #2-M.

Five selected Section 349 technicians simulated hand soldering and manual cleaning of printed wiring assemblies for two hours (one hour for each solvent) using the new solvents. Figure 5 shows the authors discussing a point prior to the initiation of the test. Figure 6 shows the technicians seated in the assembly room working at their work stations. Figure 7 shows one of the authors and a member of the JPL Environmental Affairs Section observing the technicians' activities during the 8-hr TWA test. The TWA determines whether the technicians can use each solvent under normal working conditions in a normal working environment without exceeding the solvent's permissible exposure limit (PEL). For Solvent #2-M, the PEL is 200 ppm; for Solvent #1-M it is 50 ppm. This latter figure was set by Solvent #1-M's manufacturer; it may be revised up to 100 ppm.

Each technician performed manual assembly on a dummy PWB at her work station. Since all technicians worked continuously during the test, it constituted a worst case exposure to the solvent. Figures 8 and 9 show two separate technicians simulating assembling a CCA at her workstation. In Figure 8, the cleaning agent dispenser bottle can be seen at the center-right of the photograph at the upper right corner of the board. In several cases, the technician also got up, went into another room with a fume hood, and performed cleaning off the entire assembly using the particular solvent being tested. This activity is displayed in Figure 10.

The Solvent #1-M test was performed in the morning. Each technician had attached to her an activated charcoal tube and a small pump that drew room air through the tube. The tubes were analyzed using gas chromatography to determine the amount of solvent to which each technician was exposed. In the case of Solvent #1-M, the test was set up and conducted by JPL Safety Operations. The results are presented in Table 3 below; the figures given in Table 3 (Row 1) are only for the amount of HCFC to which each technician was exposed.

**Table 3: Results of 8-Hr. Time Weighted Average (TWA) Testing**

Solvent	Technician #1 ppm	Technician #2 ppm	Technician #3 ppm	Technician #4 ppm	Technician #5 ppm	Back-ground ppm
Solvent #1-M	26.0	22.0	86.0	25.0	95.0	2.0
Solvent #2-M	20.4	15.6	55.3	—	—	—

The Solvent #2-M test was conducted in the early afternoon. Since one of the technicians could not be present for this test, only three rather than five actually participated. As with the Solvent #1-M, each technician had attached to her an activated charcoal tube and a small pump that drew room air

- 1 = No effective odor.

The results are reported in Table 2 below. Based on these results, the following ranking was obtained:

Solvent #6 (not tested) >> Solvent #4 (n-propyl bromide) >> TCA > Solvent #1-M (HCFC/EtOH/cyclohexane) > Solvent #5 (VMS) > Solvent #2-M (HFC/t-DCE/MeOH/cyclopentane)

where > indicates the solvent exhibited a more obnoxious odor.

**Table 2: Solvent Odor Test**

<b>Solvent</b>	<b>Person # 1</b>	<b>Person # 2</b>	<b>Person # 3</b>	<b>Person # 4</b>	<b>Person # 5</b>	<b>Ave.</b>
<b>TCA (control)</b>	7	6	1	3	5	4.4
<b>Solvent #1-M</b>	3	6	1	2	3	3.0
<b>Solvent #2-M</b>	3	1	1	2	1	1.6
<b>Solvent #4</b>	10	9	4	3	7	6.6
<b>Solvent #5</b>	2	2	1	2	4	2.2
<b>Solvent #6*</b>	10	10	10	10	10	10.0

Note: Solvent #3 also has a pungent odor, but it wasn't tested since it had already been eliminated as a candidate.

\*Solvent #6 is also a form of HFC; in fact, it was trifluoromethylbenzene ( $C_7H_5F_3$ ). This material had a very powerful, disagreeable odor. It wasn't considered as a TCA replacement candidate, but it was used in the odor test as an upper limit for unacceptable odor.

Based on all the results up to this point, it was decided to drop Solvents #4 and #5, and proceed with Solvents #1-M and #2-M.



- There was a genuine concern that the removed flux, having been rendered volatile, might redeposit on the hardware.

For these reasons, this method of cleaning was not pursued further.

2 Solvent #1. Although in general this material, the stabilized azeotrope of the HCFC isomers and ethyl alcohol, rendered good results, it often left an unacceptable white residue (WR). The manufacturer was consulted, and a modified solvent was recommended. In addition to the two HCFC isomers and ethyl alcohol, the modified solvent also contained cyclohexane. In this paper, this modified solvent is designated as Solvent #1-M. This material worked quite well in all respects and was considered to be a candidate for final consideration. The modified material (Solvent #1-M) investigated was an azeotrope-like formulation containing the following ingredients:

- HCFC Isomer #1 38.3 wt. %
- HCFC Isomer #2 46.8 wt. %
- Cyclohexane 10.0 wt. %
- Ethyl alcohol (EtOH) 4.5 wt. %
- Stabilizers 0.4 wt. %.

3 Solvent #2. Although in general this material, the stabilized azeotrope-like solvent consisting of the HFC, t-DCE, MeOH, and MeNO<sub>2</sub>, rendered good results, it also often left an unacceptable white residue (WR). The manufacturer was consulted, and a modified solvent was recommended. In addition to the cited ingredients, the modified solvent also contained cyclopentane. In this paper, this modified solvent is designated as Solvent #2-M. This material worked quite well in all respects and was also considered to be a candidate for final consideration. The modified material (Solvent #2-M) investigated was an azeotrope-like formulation containing the following ingredients:

- HFC 53.5 wt. %
- Trans-1,2-dichloroethylene (t-DCE) 25.0 wt. %
- Cyclopentane 15.0 wt. %
- Methanol (MeOH) 6.0 wt. %
- Nitromethane (MeNO<sub>2</sub>) 0.5 wt. %.

4 Solvent #3. When a 3-D model was run to arrive at an ODP value for this material, it emerged unacceptably high, that is, Solvent #3's ODP > 0.1. Hence, it was withdrawn from any further consideration. It did, however, clean in an acceptable fashion.

5 Solvent #4. This material did clean in an acceptable fashion, but it had, in the opinion, of many of the technicians, a powerful and unpleasant odor. See Table 2.

6 Solvent #5. Upon evaluation, this material did not remove flux any better than IPA. Hence, it was withdrawn from any further consideration.

### Odor Test

Because odor can be an important factor, especially for situations calling for manual cleaning, it was decided to run a test utilizing five different technicians to determine the extent of how offensive the odor actually was of the various cleaning agents under consideration. Admittedly this test was qualitative. The scale used was:

- 10 = Worst case.

- Solvent #1.
- Solvent #2.
- Solvent #3.
- Solvent #4.
- Solvent #5.

A brief description of each solvent is given:

Solvent #1. This material is classified as a hydrochlorofluorocarbon (HCFC). That is, the molecule contains the following elements: hydrogen (H), chlorine (Cl), fluorine (F), and carbon (C). The original material investigated was the ethyl alcohol (EtOH) azeotrope of two closely related HCFC isomers. This material has a small, but finite, ODP, generally given as 0.03. The presence of the chlorine in the molecule causes it to have a finite ODP. Under current EPA rules, it is due to be phased out of production in 2015.

Solvent #2. This material is classified as a hydrofluorocarbon (HFC). That is, the molecule contains the following elements: hydrogen (H), fluorine (F), and carbon (C). Since the molecule contains no chlorine, it has a zero (0) ODP. The original material investigated was an azeotrope-like formulation containing the following ingredients:

- HFC 50.5 wt.%
- Trans-1,2-dichloroethylene (t-DCE) 43.0 wt.%
- Methanol (MeOH) 6.0 wt.%
- Nitromethane (MeNO<sub>2</sub>) 0.5 wt.%.

Solvent #3. This material was chlorobromomethane.

Solvent #4. This material was 1-bromopropane (n-propyl bromide).

Solvent #5. This material was a volatile methyl siloxane (VMS) designed for hand cleaning operations.

### Results of Second Set of Candidates

1 Carbon Dioxide Impingement Cleaning. This method utilized a suitable gun that directed small, solid carbon dioxide (CO<sub>2</sub>) particles at the work piece, in effect acting analogous to a sand blasting operation. That is, the contamination, in this case flux residue, was simply removed by the mechanical energy of the impinging CO<sub>2</sub> pellets.

After a careful evaluation, it was noted that this method of cleaning was not satisfactory for the following reasons:

- It was very operator-dependent to achieve adequate cleaning.
- It took an average of 3-5 minutes to remove the flux residues.
- It didn't always result in complete flux removal.